Annual Report:

Measurement of ecosystem metabolism across climatic and vegetation gradients in California for the 2013-2014 NASA AVIRIS/MASTER airborne campaign

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Project Overview

We are using the California transects for the ongoing HyspIRI Airborne campaign (Figure 1a) to comprehensively assess the potential to make spatially explicit estimates of two important parameters characterizing leaf and canopy photosynthetic capacity: the maximum rate of CO_2 carboxylation by RuBisCo (V_{cmax}), and the maximum rate of electron transport required for the regeneration of RuBP (J_{max}). These variables are typically determined using leaf gas exchange measurements. However, in this project we are applying and refining rapid spectroscopic methods (at the leaf and the canopy level) we have been developing (Ainsworth et al., 2013; Serbin et al., 2012; Serbin et al., in prep) to estimate V_{cmax} and J_{max} over broad regions and across vegetation types found in California. It follows that estimation of these variables from remotely sensed hyperspectral+thermal IR data can facilitate a better understanding of the spatial patterns and seasonal characteristics of vegetation carbon assimilation across complex landscapes using similar data to that anticipated with the NASA HyspIRI satellite mission concept. Our research relies on the simultaneous acquisition of hyperspectral and thermal infrared imagery, as estimates of canopy temperature will be crucial for an accurate characterization and scaling of V_{cmax} and J_{max} to allow for broad scale analyses as well as assimilation into ecosystem process models.

Our research is focusing primarily on two climate-elevation gradients in California (Figure 1b), spanning a vegetation gradient from desert chaparral to oak woodlands and high-elevation closed canopy forests (Table 1). We are also collecting similar data at three key UC agricultural research stations to characterize globally important agro-ecosystems, in addition to natural vegetation. This provides us a strong gradient in which to test our methods and scaling approaches in a variety of vegetation types, demography, vegetation structure, and canopy functional properties. We are deriving our maps of canopy metabolism using empirical (partial least-squares regression modeling, Serbin et al., 2012) and mechanistic radiative transfer modeling (RTM) approaches with the raw AVIRIS+MASTER L2 data as well as simulated HyspIRI data being developed during the Airborne campaign. We are validating out simulated HyspIRI products of canopy metabolism using a suite of eddy covariance (EC) tower sites (Goulden et al., 2012; http://www.ess.uci.edu/~california/) located across our climate-elevation gradient (Table 1) by comparing estimates of derived from tower measurements of Gross Primary Productivity (GPP). Finally, we are also deriving and testing leaf-level estimates and
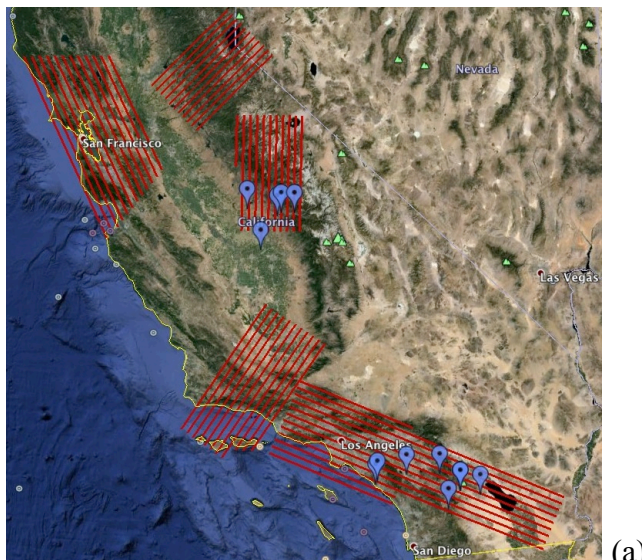
Figure 1. Location of the 12 core study sites (for details see Table 1) found within the five HyspIRI campaign flight boxes (a) and the climate-elevation EC transect (b). Currently, our focus is primarily in the southern California and Sierra/Yosemite flight boxes. During 2014 we plan to include 1-3 more sites in the Tahoe box.
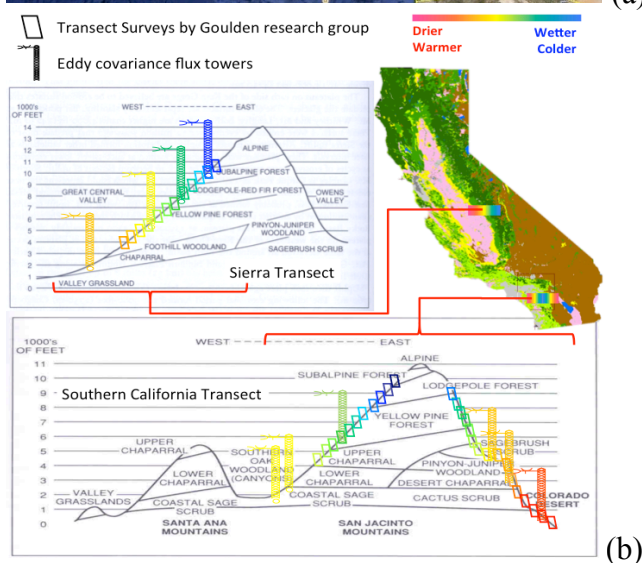
maps of vegetation functional properties (pigments, nitrogen, carbon, and lignin) using algorithms previously developed across the Upper Midwest (Serbin et al., in review; Singh et al., in prep). The idea is to test the generality of these methods to new locations as well as supplement our analysis to include properties known to influence vegetation productivity and nutrient cycling. This combined effort will yield considerable insight into the functioning of vegetation ecosystems throughout California.

Table 2. Core study sites

Site	Latitude	Longitude	Elev. (m)	Collection Dates (2013)	Vegetation
Loma Ridge Coastal Sage (EC)	33.727	-117.693	480	March-April	Coastal sagebrush
Loma Ridge Coastal Grassland (EC)	33.727	-117.693	480	March-April	Coastal grassland
South Coast Research and Extension Center (Ag)	33.633	-117.677	88	March-April	Avocado, citrus
Sky Oaks (EC)	33.380	-116.630	1397	June	Montane chaparral
Coachella Valley Agricultural Research Station (Ag)	33.544	-116.147	-27	June	Red pepper, grape
Pinyon/Juniper (EC)	33.592	-116.448	1208	not sampled	Pinyon pine, juniper
Desert chaparral (EC)	33.596	-116.445	1171	not sampled	Arid chaparral
San Jacinto James Reserve (EC)	33.803	-116.753	1325	March-April, June	Oaks, cedar, pines
Kearney Agricultural Research Station (Ag)	36.573	-119.500	115	June	Pistachio
San Joaquin Experimental Range (EC,N)	37.079	-119.720	352	March-April, June	Foothills pine, oaks, annual grasses
Soaproot Saddle (EC,N)	37.029	-119.256	1166	June	Ponderosa pine, oak
Providence Creek (EC)	37.067	-119.195	2016	June	Mixed conifer
Shorthair (EC)	37.067	-118.987	2703	not sampled	Lodgepole pine, Sub-alpine fir

EC: Site with an eddy covariance tower
Ag: Agricultural site
N: NEON site

Progress Report

Overall Project Plan

The overall project contains these primary objectives:

(1) Derivation of V_{cmax} and J_{max} at the leaf level by the combination of spectroscopy (leaf reflectance and transmittance) with combined gas exchange and chlorophyll fluorescence measurements (using the LiCor 6400 with the LI6400-40 leaf chamber fluorometer) at the study sites (Table 1, Figure 2). We are currently combining these measurements with a similar dataset from the Upper Midwest (Ainsworth et al., 2013; Serbin et al., 2012; Serbin et al., in prep) to develop a generalized algorithm for determination of leaf metabolism;

(2) Scaling of leaf-level estimates of V_{cmax} and J_{max} to the canopy using measurements of canopy composition and structure in conjunction with an empirical PLSR and radiative transfer modeling approach using the 4SAIL2 model (Verhouef and Bach, 2007). Because the rate of photosynthesis (and thus the values of V_{cmax} and J_{max}) is highly

temperature dependent, we are utilizing the MASTER data to properly retrieve the metabolic parameters and scale to a common temperature (V_{cmax} and J_{max} at 25 °C). Our RTM approach is based on a lookup table (LUT) inversion method that accounts for the uncertainties in measurements and the RTM;

(3) Inform a simple ecosystem model with EC tower observations of GPP through a Bayesian parameter inversion to estimate tower-scale V_{cmax} and J_{max}. These data are used to evaluate the maps of photosynthetic capacity across space and time within the footprint of each EC tower;

(4) Utilize the validated maps of V_{cmax} and J_{max} to generate seasonal GPP maps across the HyspIRI flight boxes to diagnose the seasonal and spatial patterns of ecosystem productivity.

(5) Validate and utilize existing algorithms (Serbin et al., in review; Singh et al., in prep) for mapping foliar chemical and morphological traits (N, C, lignin, SLA) to pair these maps with V_{cmax} and J_{max} to better understand ecosystem functioning and nutrient cycling across California.

Our year 1 efforts have focused on vegetation sampling across two HyspIRI flight boxes, the Southern California box and the Sierra/Yosemite box (Figure 1a). We collected data within the footprints of the EC towers as well as within agricultural sites in order to capture the gradient in vegetation productivity across California. To support our project, we are planning additional sampling during the 2014 airborne campaign. We plan to revisit sites as well as include 1-3 more sample locations to further capture the diversity of vegetation and the strong climate-mediated vegetation dynamics over the growing season.


Laboratory Analysis – AVIRIS & MASTER Imagery

All of the AVIRIS and MASTER images from the first two airborne campaigns from 2013 have been archived at the UW – Madison. We are now applying our pre-processing methods (Singh et al., in prep.) to correct for cross-track illumination (required for N-S or S-N oriented flightlines), atmospheric effects (convert radiance to reflectance), topography and geo-location. Once completed, we will be applying existing algorithms to convert the images to maps of foliar chemistry and will be validated with associated field measurements. Preliminary development and testing of V_{cmax} and J_{max} algorithms is currently underway.

Table 2. Summary of measurements made at each site		
Measurement	**Methods**	**Observation**
Leaf reflectance & transmittance	ASD FS3, Spec. Evolution PSM-3500, ASD integrating sphere	Leaf optical properties, foliar traits (N, C, pigments, lignin, LMA)
Leaf photosynthesis	Li-6400 & 6400-40 fluorometer	V_{cmax} and J_{max}, pigment quenching, electron transport rate (ETR)
Leaf weight, area	Analytical balance, flatbed scanner	Leaf mass per area (LMA), leaf shape (boundary layer), leaf water
Basal area, DBH, Height	Prism, DBH tape, laser hypsometer	Canopy composition and structure

Field Sampling – Vegetation

Our primary effort in Year 1 of the project was field sampling of vegetation, and subsequent processing of the field data. We sampled vegetation at most of our primary field sites (Table 1) during the March-April, June, or both airborne campaigns. Some of the sites were heavily water stressed during the later campaigns and it was decided to wait until the following year (winter or spring 2014) to sample. At each sampled site, we collected measurements of leaf gas exchange (combined A-Ci and chlorophyll fluorescence measurements), leaf temperatures, green-leaf reflectance and transmittance using an ASD FieldSpec3, Spectral Evolution PSM-3500, and an ASD integration sphere, as well as measurements of leaf mass per area (LMA) at three levels in the canopy (top, middle, and bottom, when relevant) at several plots. Upper canopy samples (top, middle) were collected using a line launcher equipped with a rope saw in order to harvest small branches for analysis. Leaf samples of foliar reflectance/transmittance and photosynthesis (e.g. Figure 2) are being used to develop the models for estimating V_{cmax} and J_{max}. In addition, we measured plot-level composition and structure at each sample site. Table 2 provides a summary of the measurements taken in 2013.
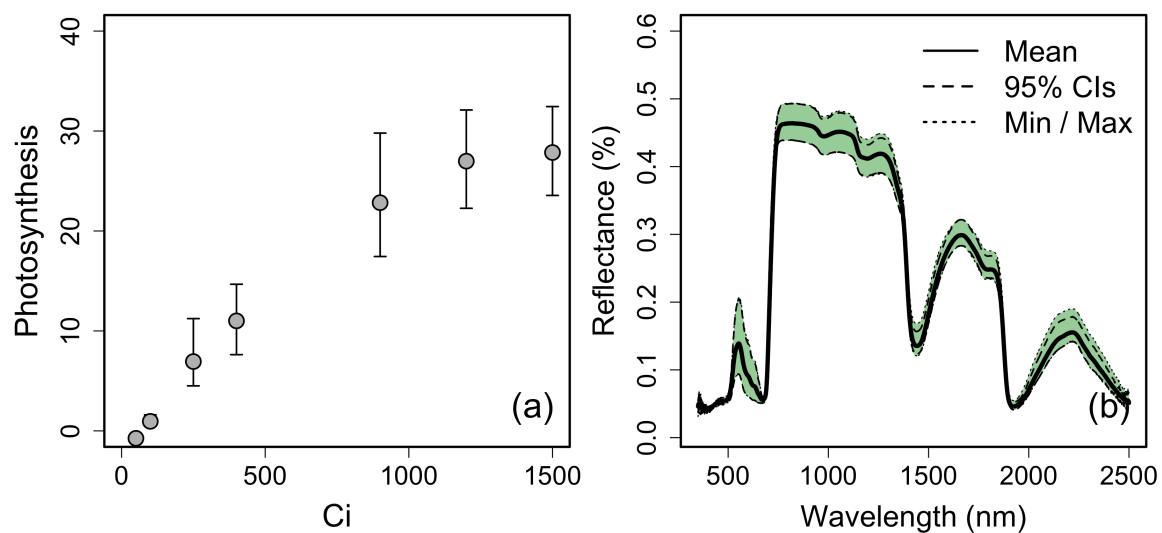
Figure 2. (A) The variation in photosynthetic metabolism (A-Ci curves) with temperature and canopy position across grape leaves located in the Coachella Valley Agricultural Research Station (CVARS). The associated variability in grape leaf reflectance (B) for the same samples as those used for gas exchange measurements.

Field Sampling – Eddy Covariance Flux Towers

We have assimilated the existing eddy covariance flux tower data from our field sites in preparation for development of a pixel-level validation data set for our maps of V_{cmax} and J_{max}. The data up to 2012 is at a level of completeness so that missing data can be inferred by gapfilling the data. We will have 2013 data in early 2014, covering the periods of AVIRIS acquisition over our sites. However, the previous year's data will allow us to determine whether our retrievals match what should be expected based on past

climatological and phonological trends. An online flux partitioning and gapfilling tool developed by the Department of Biogeochemical Integration at the Max Planck Institute was employed in order to estimate the fluxes for times of missing data and to partition out estimates of gross primary productivity (GPP). This tool estimates values for missing data by employing the Reichstein et al. (2005) method for gapfilling which produces the gapfilled data along with quality control values explaining how each data point was estimated (which meteorological variables were used and how large a window of nearby days was averaged to estimate the point). Flux partitioning, or estimating ecosystem respiration and GPP from net ecosystem exchange (NEE), uses the original data of high quality to estimate nighttime respiration, from which ecosystem respiration can be inferred and thus GPP. We then calculated a daily average for the gapfilled and partitioned data and compared between sites. As expected, productivity increases with increasing altitude in the Southern California sites, and increases with increasing elevation in the Yosemite sites to a point, but slightly declines at high elevations due to the cooler climate limiting growing days. Figure 3 shows NEE for seven of our sites for the most recent years of record. These data will be inverted into canopy-level estimates of V_{cmax} and J_{max} following methods detailed in the original proposal, and linked to the results of leaf level A-Ci analysis (Figure 2A) and resulting maps.

Laboratory Analysis – Vegetation

In addition to the fresh, green-leaf spectra we are also collected spectra on dried and ground leaf samples. These data will be used as an additional set of data for deriving leaf chemical properties using existing algorithms (Serbin et al., in review). Leaf samples from the field were dried for 72 hours at 70˚C, and finely ground to pass through 60-mesh filter. All samples are weighed and then stored in a dessiccator prior to analysis. Using these samples, we are determining the carbon, nitrogen, and lignin concentrations using spectroscopic methods. We are deriving LMA with the measurements of dried leaf mass and leaf area scans (Serbin et al., in review). Using these data, in conjunction with the green-leaf spectra we are developing canopy-scale estimates of these traits for each sample plot in order to validation maps of canopy chemistry derived with AVIRIS data and existing models (Singh et al., in prep).

Data Analysis and Synthesis

It is too early in the project to present substantial results; however, we have generated some preliminary summaries of our field data. Analyses of leaf gas exchange measurements are showing significant variation between species and within vegetation canopies (e.g. Figure 2A). We are also observing significant differences in properties within a species related to changes in elevation, and this climate and water status. Observations of leaf optical properties are showing strong within canopy variability (e.g. Figure 2B), as well as strong seasonal patterns from leaf-out to mid-summer values. LMA and foliar chemistry shows strong spatial patterns related to differences in species composition. Drawing from this effort and our previous work, we have developed a preliminary calibration equation to estimate V_{cmax} from spectroscopy (Figure 4).
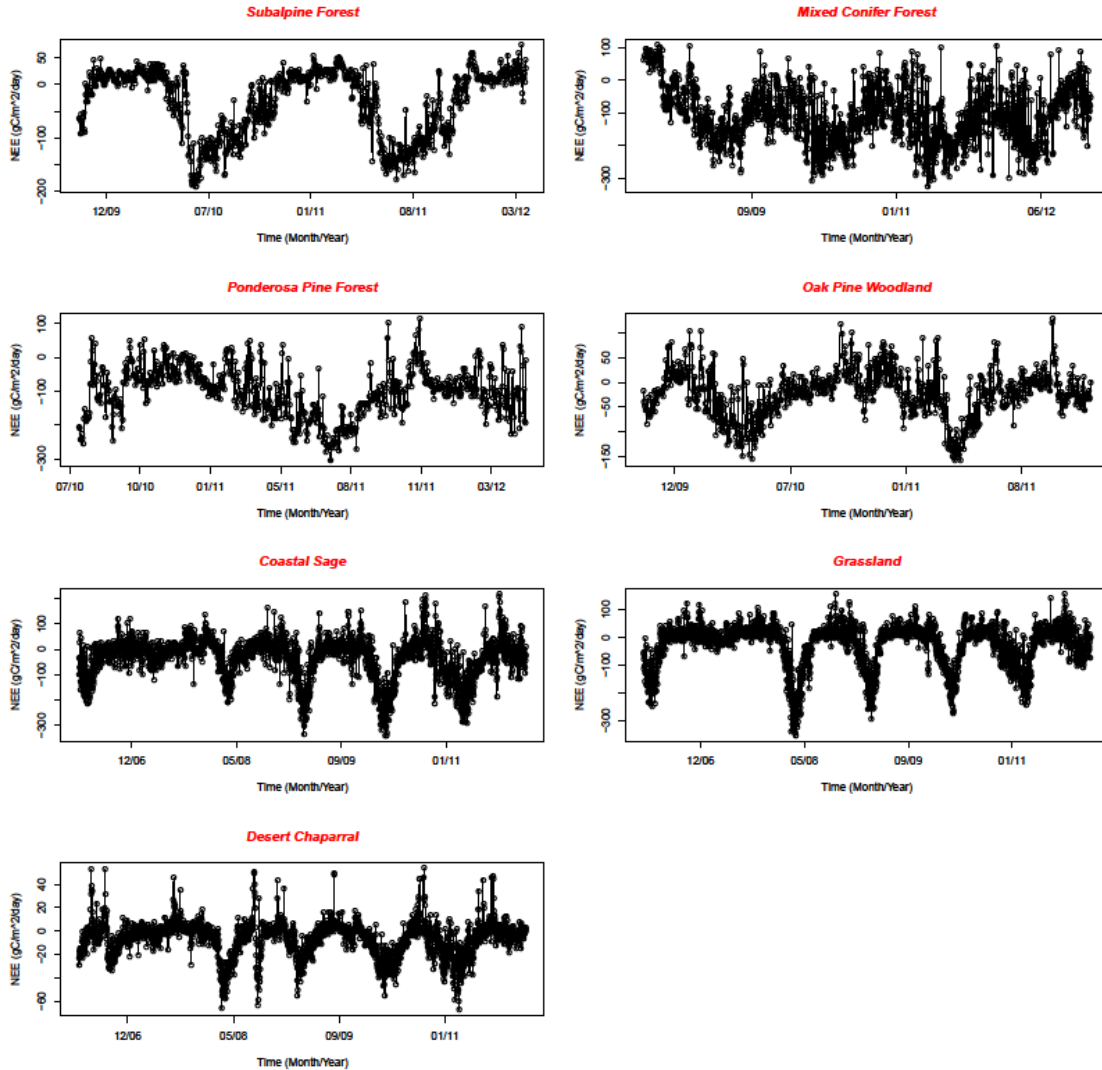
Figure 1: Daily net ecosystem exchange (NEE) values for four sites from the Sierran Transect (Subalpine Forest, Mixed Conifer Forest, Ponderosa Pine Forest, and Oak Pine Woodland) and three from the Southern California Transect (Coastal Sage, Grassland, and Desert Chaparral). The difference between transects is apparent in the growing season, as sites located in the Sierra Transect are productive for most of the spring and summer months, while the sites located in the Southern California sites are very productive during a very short window early in the year and are then dormant. Within the Sierra Transect, the most productive ecosystems are the Mixed Conifer Forest and the Ponderosa Pine forest, both of which are located in the middle of the elevation transect. This can be explained by the moderate climate experience at these locales compared to the Subalpine Forest (limited by temperature) and the Oak Pine Woodland (limited by water). Within the Southern California Transect, the Coastal Sage and Grassland ecosystems are more productive than the Desert Chaparral, with the latter being impacted by water and heat stress.
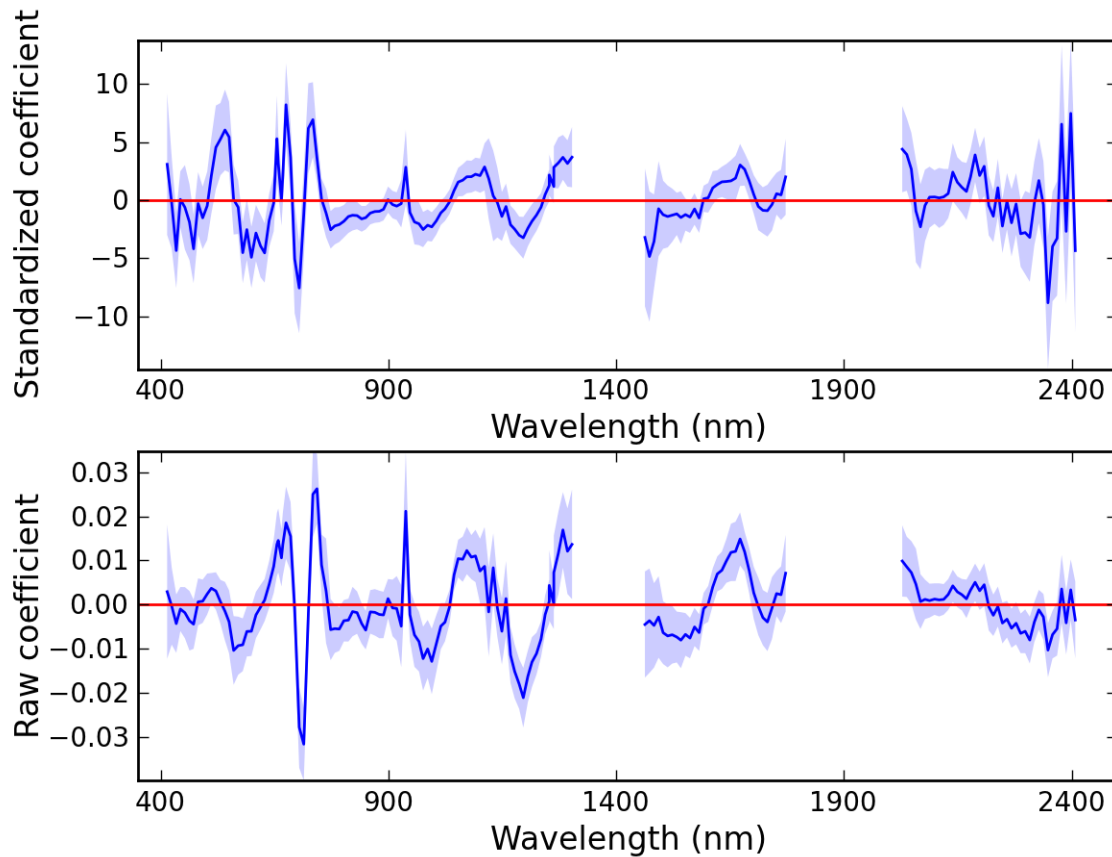
Figure 4. Preliminary calibration coefficients for mapping V_{cmax} from AVIRIS spectra.

Collaborative Activities

In addition to data collection for our research, we have been involved in fruitful collaborations with the groups at UC-Davis (Ustin group), UC Santa Barbara (Roberts group), and Sonoma State (Clark's group). For example, we have provided a large number of foliar samples for analysis of pigment composition, including carotenoids, in order to aid in the refinement of modeling leaf optical properties. In addition, we have been collaborating with various groups to aid in the processing of spectral observations using a custom R package developed for QA/QC and processing of spectral data (R-FieldSpec; https://github.com/serbinsh/R-FieldSpec). Finally, we worked closely with the groups from NEON and RIT during the June campaign to provide canopy samples and spectral observations at the SJER and Soaproot sites.

Project Staffing

The field and analytical components of the research are being led by post-doctoral research associate Shawn Serbin. Dr. Serbin led reconnaissance fieldwork in February, 2013, development of field protocols, as well as month-long sampling campaigns in the campaign footprints during the AVIRIS California flights in March-April and May-June

of 2013. Serbin has overseen all processing of field measurements, as well as supervision of image processing activities.

Overall project lead is <u>Phil Townsend</u>, who has overseen the development of spectroscopic protocols, and participated in fieldwork in March and June of 2013. Townsend is the intellectual lead on AVIRIS processing activities based on past efforts. Townsend has worked with Serbin to explore methods of scaling leaf-level spectroscopic estimation of metabolic capacity to AVIRIS spectra.

<u>Eric Kruger</u> has helped coordinate planning and logistics activities, including initial site reconnaissance in southern and central California in February, and subsequent participation in field measurement campaigns at research sites in southern and central in March and again in June. In those campaigns, Kruger assisted in the acquisition of leaf gas exchange data used to generate estimates of two key parameters characterizing leaf photosynthetic capacity—V_{cmax} and J_{max}. Kruger has since been exploring other facets of the gas exchange data, such as possible links between stomatal conductance and estimates of electron transport rate, which, in turn, may be estimable from leaf reflectance spectra.

<u>Ankur Desai</u> has overseen the collection of eddy covariance (EC) flux data to be used to validate HyspIRI-derived retrievals. Processing of EC data is underway by MS student <u>Sean DuBois</u>, under supervision of Desai.

In addition, we have been assisted by Clayton Kingdon (research specialist: fieldwork, spectroscopy, image processing), Ryan Geygan (research intern: fieldwork), Ben Spaier (LTE: fieldwork), and Robert Phetteplace (undergraduate: fieldwork and image processing).

Citations

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